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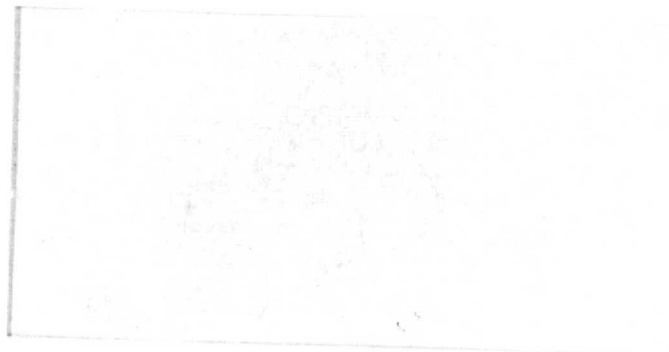
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MISSILES & SPACE COMPANY, INC. • SUNNYVALE, CALIFORNIA
A SUBSIDIARY OF LOCKHEED AIRCRAFT CORPORATION

SPACELAB SCRUBBER ANALYSIS
AND TEST SUPPORT
FINAL REPORT

SEPTEMBER 30, 1979

PREPARED UNDER CONTRACT NAS 8-32628

BY

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FOR

NATIONAL AERONAUTICS & SPACE ADMINISTRATION
MARSHALL SPACE FLIGHT CENTER

TABLE OF CONTENTS

	<u>Page</u>
INTRODUCTION	1
CONTAMINANT SELECTION, INTRODUCTION AND INBLEED RATE DETERMINATION	2
TEST CHAMBER CONTAMINANT CONCENTRATION PREDICTIONS	10
DEVELOPMENT TEST	15
Test Results - Ammonia	17
Test Results - Carbon Monoxide	19
Test Results - Freon 22	22
Test Results - Toluene and Xylene	22
Test Results - Dichloromethane and F113	25
Review of Scrubber Design	25
QUALIFICATION TEST	28
COMPUTER PROGRAM MODIFICATIONS	30
Intermittent Low Concentrations	30
Nonconvergent Solution	30

ILLUSTRATIONS

<u>Figure No.</u>		<u>Page</u>
1	Development Test Setup	16
2	Spacelab Scrubber Development Test Results - Ammonia	18
3	Spacelab Scrubber Development Test Results - Carbon Monoxide	20
4	Spacelab Scrubber Development Test Results - Freon 22	23
5	Spacelab Scrubber Development Test Results - Toluene and Xylene	24
6	Spacelab Scrubber Development Test Results - F113 & Dichloromethane	26

LIST OF TABLES

<u>Table</u>		<u>Page</u>
1	Selection of Candidate Inbleed Contaminants	3
2	Candidate Inbleed Contaminants	6
3	Candidate Inbleed Contaminants	7
4	Spacelab Scrubber Calculation Summary	12
5	Spacelab Scrubber Calculation Summary	13
6	Daily Concentration Data	31

INTRODUCTION

The Spacelab Scrubber Development Test program was a follow-on to three previous contracts that dealt with the Spacelab contaminant problem. These three contracts and the work accomplished under them are as follows:

- o Contract NAS 8-31551 Development of a Computer Program for Space-lab Contaminant Control Analysis. NASA component and vehicle test data were analyzed to prepare a contaminant load model representative of Spacelab loads. A computer program was developed to predict the performance of the Spacelab baseline contaminant control system. Calculation coefficients were established to correlate computer results with NASA test data. Computer analysis showed that the baseline system was satisfactory except for removal of ammonia, carbon monoxide and several other contaminants. An add-on charcoal canister including acid treated charcoal for ammonia removal and an oxidation catalyst for carbon monoxide removal was selected and sized.
- o Contract NAS 8-31960 Investigation & Testing of Low Temperature Carbon Monoxide Catalysts. This contract selected and performance tested a low temperature carbon monoxide oxidation catalyst by surveying the available literature, screening candidate catalysts, evaluating the performance of the most promising catalysts by tests, selecting a preferred catalyst and finally conducting poisoning and simulated mission performance tests.
- o Contract NAS 8-32400 A Generalized Computer Program for Trace Contaminant Control. The computer program developed under contract NAS 8-31551 was improved upon by adding a more sophisticated charcoal bed analysis technique and by making the program suitable for the Univac 1100.

The Spacelab Scrubber Development test program was the next step in the Spacelab contaminant control system development effort. This contract was to support NASA-MSFC in the conduct of development and qualification tests of the add-on charcoal bed (Scrubber). The contract tasks included establishment of the contaminants to be used in the tests, the rates and methods of introduction, prediction of contaminant levels to be achieved in the tests and review and analysis of test results.

CONTAMINANT SELECTION, INTRODUCTION AND INBLEED RATE DETERMINATION

The first step in the Scrubber Development Test program was the selection of contaminants to be used in the development and qualification tests. Five different criteria were used to select the contaminants for test giving priorities to each as follows.

A Univac 1110 run was made with all Spacelab contaminants introduced into the baseline system without the add-on charcoal bed. This run was made to establish those contaminants that are greater than or near SMAC without the add-on charcoal bed. This was the first step toward establishing those contaminants that were to be used to qualify the add-on charcoal bed. The percent of SMAC was assigned a priority 3 in selecting contaminants for test and are listed in Table 1. The second step was a TYMSHARE run with 18 contaminants taken from the Univac run (the highest percentage of SMAC). The TYMSHARE run included the baseline system and the add-on charcoal bed. The results of this run were used to calculate the quantity of each contaminant absorbed by the add-on charcoal bed and are listed in Table 1.

The quantity of each contaminant absorbed by the add-on charcoal bed was given a priority 2 in selecting test contaminants.

Priority 1 for test contaminant selection was given to those contaminants that are not controlled by cabin accumulation as determined by a computer run with all contaminants and no removal system in the Spacelab. If the baseline system does not remove these contaminants then the add-on bed must. It is these contaminants that are the most of concern in the design of a contaminant control system.

Table 1
Selection of Candidate Inbleed Contaminants

<u>Priority No. 1</u> Contaminants Not Controlled By Cabin Accumulation	<u>Priority No. 2</u> Qty. of Contaminants Absorbed by Add- On Charcoal Bed (mg/hr)	<u>Priority No. 3</u> % of MAC Without Add-On Bed In System
*1) Ammonia	*1) Dichloromethane	55
*2) Carbon Monoxide	*2) Toluene	33
*3) Methyl Alcohol	*3) Carbon Monoxide	31
*4) Trichloroethane	*4) Freon 113	29
*5) Toluene	*5) Freon 22	18
*6) Dichloromethane	*6) Ammonia	17
*7) Phenol	*7) Xylene	6
*8) Cyclohexanol	8) Butyraldehyde	4
*9) Benzene	*9) Cyclohexanol	4
10) Acrolein	*10) Methyl Alcohol	4
11) Allyl Alcohol	11) Methyl Isobutyl Ketone	3
12) Butyl Lactate	*12) Trichloroethane	3
*13) Trimethyl Benzene	*13) n-Butyl Alcohol	3
14) Isopropyl Alcohol	*14) Tri-Methyl Benzene	1
15) Methyl Ethyl Ketone	*15) Benzene	1
*16) n-Butyl Alcohol	*16) Phenol	$\frac{1}{2}$
*17) Xylene	17) Propandiene	NIL
*18) Freon 113	18) Furan	NIL
	*1) Carbon Monoxide	517
	*2) Ammonia	130
	*3) Dichloromethane	107
	*4) Trichloroethane	47
	*5) Freon 22	30
	*6) Benzene	26
	*7) Toluene	21
	*8) Phenol	13
	*9) Cyclohexanol	10
	*10) Furan	9
	*11) n-Butyl Alcohol	6
	12) Propadiene	5
	13) Methyl Alcohol	5
	*14) Trimethyl Benzene	5
	*15) Freon 113	5
	16) Methyl Isobutyl Ketone	4
	*17) Xylene	4
	18) Butraldehyde	3

*Selected Candidate Inbleed Contaminant

Table 1 (continued)

Selection of Candidate Inbleed Contaminants

Priority No. 4		Priority No. 5		
Charcoal "A" Value		Total Production Rate		
		mg/hr		
*1)	Xylene	8.6	*1) Toluene	97
*2)	Cyclohexanol	8.8	*2) Dichloromethane	96
*3)	Trimethyl Benzene	9.1	*3) Methyl Alcohol	90
4)	Methyl Isobutyl Ketone	10.0	*4) Freon 113	82
*5)	Toluene	10.1	*5) Freon 22	49
*6)	Phenol	10.9	*6) Ammonia	49
*7)	n-Butyl Alcohol	12.3	*7) Carbon Monoxide	38
*8)	Freon 113	13.2	8) Acetone	33
*9)	Trichloroethane	16.1	9) Isopropyl Alcohol	27
10)	Butyaldehyde	17.5	*10) Xylene	20
11)	Cyclohexane	17.7	11) Trifluoro Chloro Ethylene	18
12)	Isopropyl Acetate	18.2	12) Cyclohexane	17
*13)	Benzene	18.3	*13) Cyclohexanol	12
*14)	Dichloromethane	20.8	14) Butyraldehyde	12
15)	Isopropyl Alcohol	22.5	15) Methyl Isobutyl Acetate	10
16)	Methyl Ethyl Ketone	22.7	16) Isopropyl Acetate	9
*17)	Freon 22	27.5	*17) Trichloroethane	8
18)	Acetone	27.7	18) Methyl Ethyl Ketone	8
19)	Propadiene	29.7	*19) n-Butyl Alcohol	7
20)	Furan	38.2	*20) Trimethyl Benzene	4
*21)	Methyl Alcohol	39.5	*21) Benzene	2
			*22) Phenol	1.3

*Selected Candidate Inbleed Contaminant

Charcoal "A" values were calculated for all contaminants in Table 1, and were assigned a priority 4 in the selection of test contaminants. It was desired to select contaminants with a broad range of "A" values to check the co-adsorption characteristics of the add-on charcoal bed. The "A" values are presented in the fourth column of Table 1.

The fifth priority of test contaminant selection was the total contaminant generation rate. Table 1 lists those rates for all of the contaminants in the other columns of Table 1.

Fourteen contaminants were then selected for further consideration by inspection of the five columns in Table 1. These fourteen contaminants were those that were high on all or almost all of the five priority lists in Table 1. The range in "A" values is from 8.6 to 39.5.

The last remaining task in the selection of test contaminants, was the study of the inbleed rates and resultant test chamber concentrations. The inbleed rates were calculated by dividing the quantity of contaminant absorbed by the add-on bed in seven days to derive an average inbleed rate. To these numbers were added an allowance for test chamber accumulation which was calculated by multiplying the seventh day contaminant concentration by the test chamber volume and dividing by the number of hours in seven days. If the add-on charcoal bed performed as predicted by the computer program then it should absorb the quantity of each contaminant shown by column 2 of Table 2 and produces a test chamber concentration equal to that predicted by the computer program run. Values of these variables were calculated and are presented by Table 2. An analysis was then made to determine the ability to control these relatively low inbleed rates and to measure the low chamber contaminant concentrations associated with some of these contaminants. Table 3 presents a summary of the conclusions of this analysis. A plus next to the contaminant concentration in Table 3 indicates that the contaminant could be directly measured at the concentration listed. A minus means that concentration of the sample by cold

Table 2 Candidate Inbleed Contaminants

	<u>Contaminant Inbleed Rate</u>		<u>Test Chamber Concentration</u>	
	(mg/hr)	(cc/day)	(mg/m ³)	(ppm)
1) Dichloromethane	54.5	0.98	28.5	8.2
2) Toluene	32.7	0.91	15.3	4.1
3) Carbon Monoxide	31.2	644	17.1	14.9
4) Freon 113	28.7	86.1	13.7	1.8
5) Freon 22	18.1	119	68.2	19.3
6) Ammonia	17.6	596	8.1	11.7
7) Xylene	6.4	0.18	3.0	0.7
8) Cyclohexanol	3.8	0.10	1.8	0.4
9) Methyl Alcohol	3.6	0.11	8.8	6.7
10) Trichloroethane	2.7	0.045	1.3	0.2
11) n-Butyl Alcohol	2.5	0.074	1.2	0.4
12) Trimethyl Benzene	1.3	0.04	0.6	0.1
13) Benzene	0.7	0.02	0.3	0.1
14) Phenol	0.4	0.01	0.2	0.05

Table 3 Candidate Inbleed Contaminants

	<u>Contaminant Inbleed Rate</u> <u>(Based on Charcoal Bed Data)</u>		<u>Test Chamber Concentration</u>		<u>Class**</u>	<u>Water Solubility</u> gm/100cc	<u>Recommended Inbleed Rate</u> mg/hr
	(mg/hr)	(cc/day)	(mg/m ³)	(ppm)			
*1) Dichloromethane	54.5	0.98	28.5	8.2 ⁺	UW	2	95.6
*2) Toluene	32.7	0.91	15.3	4.1 ⁺	OW	nil	97.2
*3) Carbon Monoxide	31.2	644	17.1	14.9 ⁺	Gas	-	38.6
*4) Freon 113	28.7	0.44	13.7	1.8 ⁺	UW	nil	82.7
*5) Freon 22	18.1	119	68.2	19.3 ⁺	Gas	-	49.3
*6) Ammonia	17.6	596	8.1	11.7 ⁺	Gas	-	17.6
*7) Xylene	6.4	0.18	3.0	0.7 ⁺	OW	nil	20.2
8) Cyclohexanol	3.8	0.10	1.8	0.4 ⁻	WS	5.7	0
99) Methyl Alcohol	3.6	0.11	8.8	6.7 ⁺	WS	∞	0
10) Trichloroethane	2.7	0.045	1.3	0.2 ⁻	UW	nil	0
11) n-Butyl Alcohol	2.5	0.074	1.2	0.4 ⁻	WS	7.9	0
12) Trimethyl Benzene	1.3	0.04	0.6	0.1 ⁻	OW	nil	0
13) Benzene	0.7	0.02	0.3	0.1 ⁻	OW	nil	0
14) Phenol	0.4	0.01	0.2	0.05 ⁻	WS	6.7	0

*Recommended Test Contaminant

**UW - Heavier than Water (Underwater)

OW - Lighter than Water (Overwater)

WS - Water Soluble

trapping or other means would probably be required. Contaminants with a minus were eliminated from further consideration.

The next step in the contaminant selection was to classify each contaminant as to solubility and density to determine introduction method. Table 3 includes a column that indicates whether a contaminant was water soluble (WS), heavier than water (underwater UW), lighter than water (overwater), or a gas. Another column in Table 3 presents the water solubility in gms of contaminant per 100 ml of water. The advantage of water soluble contaminants is that they can be dissolved in water to give a volume of mixture that can be readily pumped into the test chamber. The disadvantage of this approach is, however, that condensation will occur as the chamber humidity rises to 100%. Addition of a condensing heat exchanger complicates the test setup and introduces an unwanted contaminant removal device.

The underwater and overwater contaminants listed in Table 3 can be introduced by pumping water into a graduated cylinder containing the contaminants and displacing them into the test chamber. Pumping water instead of pure contaminant avoids the problems of materials compatibility with the pump tubing. The contaminant introduction rates for these contaminants are so low, (less than 1 cc per day) that they could not be continuously introduced by a pump. They could be syringe injected or the pump could be run periodically. The latter approach was selected.

Gaseous contaminants were introduced by mixing them with gaseous nitrogen in a pressurized bottle and bleeding them in at fixed rates through flowmeters. Inbleed flows for the gaseous contaminants are listed below:

<u>Contaminant</u>	<u>Pure Contaminant Inbleed Rate (mg/hr)</u>	<u>Gas Mixture (%)</u>	<u>Gas Mixture Inbleed Rate (cc/min)</u>
Carbon Monoxide	31.2	3% CO	14.9
Freon 22	18.1	1% F22	8.3
Ammonia	17.6 **	5% NH ₃	8.3

Introduction of gaseous contaminants in nitrogen introduces the problem that test chamber pressure would rise during the seven day test from 14.7 to 17.0 psia.

Based on the previously presented data it was recommended to NASA that:

- o The contaminants with an asterisk by them on Table 3 be selected for the test program.
- o CO, F22 and NH₃ be introduced as gases mixed with nitrogen and the test chamber be made compatible with the pressure increase.
- o Dichloromethane and Freon 113 be mixed together and introduced underwater on a periodic basis.
- o Toluene and Xylene be mixed together and introduced overwater on a periodic basis.
- o The inbleed rates of all underwater and overwater contaminants be increased to maximum production rates instead of those listed by Table 3 and the introduction pump be run approximately 10 percent of the time (6 minutes every hour).
- o The inbleed rates of carbon monoxide and Freon 22 be increased to maximum production rates to produce more favorable flowmeter readings and to stress the contaminant system to a greater degree. Pressure would increase from 14.7 to 18.2 psia with this approach.

TEST CHAMBER CONTAMINANT CONCENTRATION PREDICTIONS

A computer analysis of the test chamber contaminant concentrations during a seven day test using the recommended contaminants at their recommended introduction rates with an add-on charcoal bed showed the following values as compared to MAC.

<u>Contaminant</u>	<u>Introduction Rate (mg/hr)</u>	<u>MAC (mg/m³)</u>	<u>7 Day Concentration (mg/m³)</u>
Xylene	20.29	86.9	8.8
Toluene	97.17	75.4	42.
Dichloromethane	95.58	86.9	41.5
Freon 22	49.33	353.9	534.
Freon 113	82.67	383.4	36.
Carbon Monoxide	38.62	28.8	17.
Ammonia	17.60	17.4	7.7

None of the contaminants exceed MAC with the recommended test procedures except for Freon 22.

Several computer runs were then made to study the reasons for high Freon 22 concentrations, i.e., interference with other contaminants or just relatively poor adsorption without interference. Two new computer runs were made to determine the effects of co-adsorption on Freon 22. One run was with all contaminants at calculated inbleed rates and the other run increased Freon 22 inbleed rates to full production levels while holding all other contaminants at calculated values. Freon 22 concentrations were as follows:

<u>Run No.</u>	<u>F22 Concentration (mg/m³)</u>	<u>F22 Inbleed Rate (mg/hr)</u>	<u>All Other Contaminants</u>
Original	534	49.33	At max inbleed rates
1	150	18.08	At calculated inbleed rates
2	486	49.33	At calculated inbleed rates

The results of the runs showed that there was some effect of coadsorption (Run 2 F22 concentration is about 50 mg/m³ lower than the original run which showed that the increase in other contaminant inbleed rates increased F22 concentrations). However this increase is a second order effect with the primary effect being the increase in Freon 22 inbleed rate.

Considering the fact that quite a few changes to the computer program had been made, over the contract period, it was decided to repeat the entire contaminant inbleed calculation routine using the latest program listing. Table 4 presents the results of four computer runs that calculated expected contaminant concentrations for various inbleed rates and test chamber volumes. Table 5 presents the contaminant inbleed rates used in the runs.

Run No. 1 was a Spacelab run using full contaminant production rates for the seven selected contaminants with the baseline system plus add-on charcoal bed. This run was used to establish how much of each contaminant was removed by the add-on charcoal bed, from which test inbleed rates were calculated by the following technique:

$$\text{Inbleed Rate} = \frac{C_{\text{qty}} + C_i V_{\text{tc}}}{168} \quad (\text{mg/hr})$$

C_{qty} = amt of contaminant removed by add-on bed in seven days (mg)

C_i = spacelab contaminant concentration at seven days (mg/m³)

V_{tc} = test chamber volume (m³)

Inbleeding these rates into the test chamber should result in the same add-on bed charcoal loading and approximately the same chamber contaminant concentrations as was obtained from the Spacelab computer run.

Run No. 2 predicts the test chamber contaminant concentrations resulting from inbleeding the rates calculated from Run No. 1 into the test chamber volume containing the add-on bed only. Run No. 3 increased the test chamber contaminant inbleed rates to full Spacelab production rates to stress the bed (ammonia production rate was not increased). As expected all contaminant

Table 4 Spacelab Scrubber Calculation Summary

Contaminant	Contaminant Concentration (mg/m ³)			
	<u>Run No. 1</u> Baseline+Addon in Spacelab Vol. 2X Cont Rates	<u>Run No. 2</u> Addon Bed Only + Calc Inbleed Rates	<u>Run No. 3</u> Addon Bed Increased Bleed Rates Ex NH ₃	<u>Run No. 4</u> Addon Bed Increased Bleed Rates Ex NH ₃ & F22
Xylene	2.97	2.81	9.02	9.02
Toluene	15.3	14.4	43.2	43.2
Dichloromethane	29.4	24.5	42.5	42.5
Freon 22	85.5	87.9	534	103
Freon 113	14.8	13.7	36.7	36.7
Ammonia	11.1	10.1	10.1	10.1
Carbon Monoxide	17.1	14.0	17.2	17.2

Table 5 Spacelab Scrubber Calculation Summary

Inbleed Rates (mg/hr)

Contaminant	Run No. 1 Baseline + Addon in Spacelab Vol. 2X Cont Rates	Run No. 2 Addon Bed Only + Calc Inbleed Rates	Run No. 3 Addon Bed Increased Bleed Rates Ex NH ₃	Run No. 4 Addon Bed Increased Bleed Rates Ex NH ₃ and F22
Xylene	20.29	6.33	20.29	20.29
Toluene	97.17	32.29	97.17	97.17
Dichloromethane	95.58	55.04	95.58	95.58
Freon 22	49.33	11.37	49.33	11.37
Freon 113	82.67	30.79	82.67	82.67
Ammonia	49.08	22.75	22.75	22.75
Carbon Monoxide	38.62	31.46	38.62	38.62

concentrations rose in direct ratio to the inbleed rates except for Freon 22 which is in breakthrough and rose more than in direct proportion to the inbleed rate. All contaminant concentrations resulting from Run No. 3 were below MAC except for Freon 22 which was 534 mg/m^3 compared to an MAC of 354 mg/m^3 .

Run No. 4 calculated the test chamber concentrations resulting from full production rates for all contaminants except ammonia and Freon 22 which were held at rates calculated from Run No. 1. Freon 22 concentration was very much below MAC for this run. It was decided to use the rates in Run No. 4 for the development test of the add-on bed except that the Freon 22 introduction flowrate could not be controlled this low. The lowest controllable flow of Freon 22 (21.48 mg/hr) was therefore selected as the test chamber inbleed rate.

Following loading of the charcoal canister with untreated, acid treated, and catalyzed charcoal in preparation for the development test, the test prediction computer run was repeated using an actual loading of 3.82 kg , which represents the dry weight of untreated and acid treated charcoal. The test duration was expanded to 14 days for this run in order to assess the design margin for the charcoal canister. Contaminant inbleed rates used in the calculation and concentrations at 7 and 14 days as compared to MAC are presented below:

Contaminant	Inbleed Rate (mg/hr)	Test Chamber Concentration (mg/m ³)		MAC (mg/m ³)
		7 day	14 day	
Xylene	20.29	9.0	9.0	86.9
Toluene	97.17	43.2	43.2	75.4
Dichloromethane	95.58	42.5	82.9	86.9
Freon 22	21.48	203.	527.	353.9
Freon 113	82.67	36.7	36.7	383.4
Ammonia	22.75	10.1	10.1	17.4
Carbon Monoxide	38.62	17.2	17.2	28.8

DEVELOPMENT TEST

Figure 1 presents a schematic of the development test setup. Lockheed reviewed the test setup, contaminant introduction methods, test operations plan, and instrumentation during a trip to NASA-MSFC and concurred with all aspects of the test. The development test was conducted from September 11, 1978 to October 6, 1978. A summary of the test operations and an analysis of the test results was conducted by Lockheed.

Test Summary

1) September 11 through September 22

- o All contaminants (F113 and Dichloromethane were started late at ~60 hours)
- o Continuous testing
- o Ammonia inbleed rate increased to 1.5 times nominal at 193.5 hours
- o Carbon monoxide flow adjusted downward at 213.5 hours
- o Ammonia inbleed rate increased to 2 times nominal at 216 hours
- o Test duration ~265 hours

2) September 25 through September 29

- o Carbon monoxide and ammonia only
- o Continuous testing
- o Ammonia inbleed rate increased to 3 times nominal at 54 hours
- o Ammonia inbleed rate increased to 4 times nominal at 78 hours
- o Test duration ~98.5 hours

3) October 2 through October 6

- o Carbon monoxide and ammonia only
- o Ammonia flow at 4X
- o Test duration ~98 hours

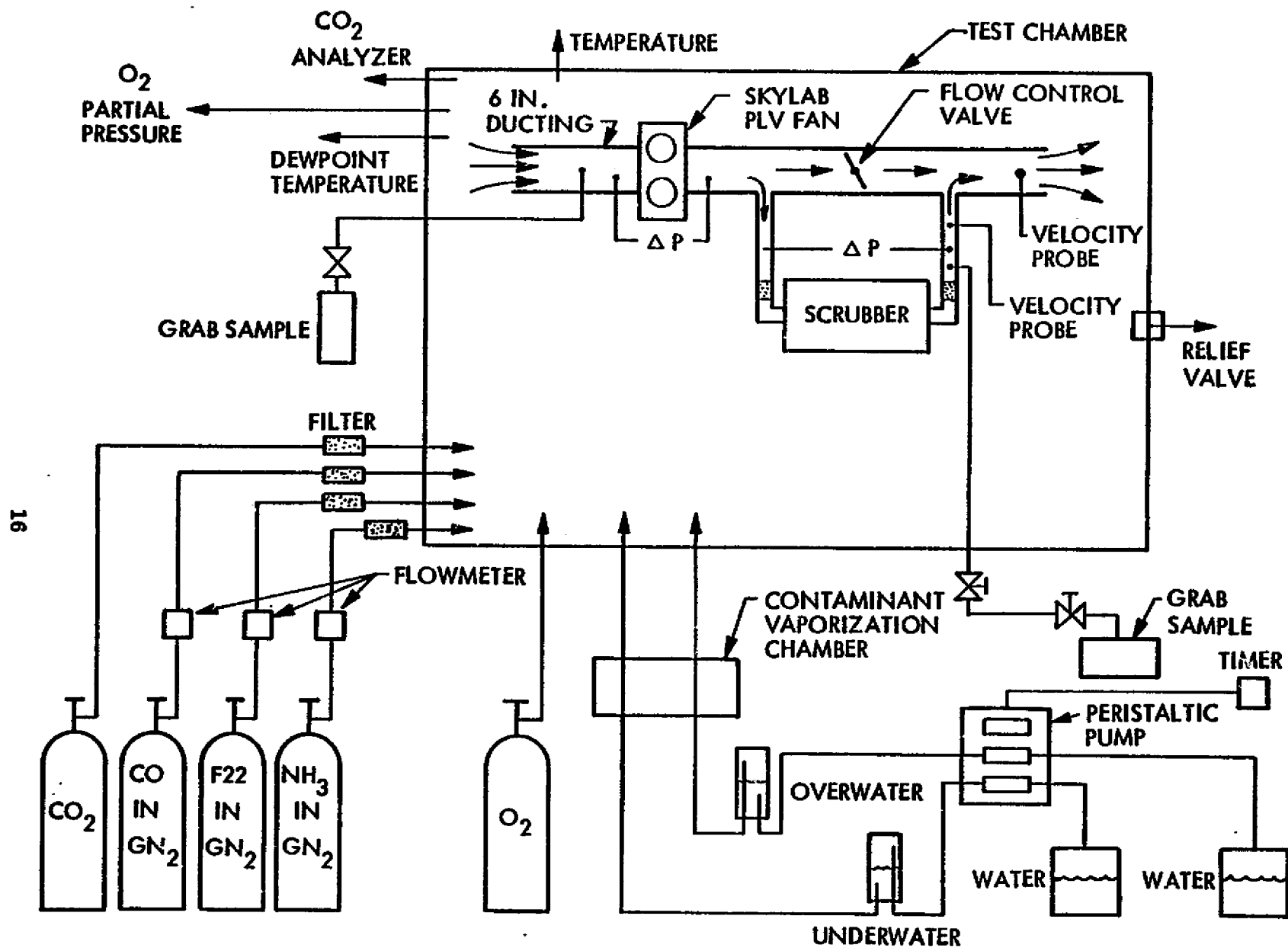


Fig. 1 Development Test Setup

Test Results - Ammonia

Figure 2 plots measured chamber and scrubber outlet ammonia concentrations versus time. Chamber ammonia concentrations were generally lower than predicted, but did respond to increases in inbleed flow rate. The most unusual event was the low concentrations prior to 140 hours. Several possible explanations were considered and checks were made to determine their probability of occurrence, as follows:

Possible Reason for Low Ammonia Reading

- o Ammonia supply bottle concentration low
- o Ammonia flowmeter inaccurate
- o Ammonia line leakage downstream of flowmeter
- o Ammonia reaction with other contaminants in heated introduction chamber
- o Ammonia reaction or adsorption on chamber walls or parts
- o Ammonia dissolving in water
- o Scrubber canister flow too high

Test System Checkout

- o Measured concentration (5.2 ppm) compares favorably to desired 4.9 ppm.
- o Flowmeter calibrated and measured ammonia concentration was correct during no removal chamber buildup checkout test.
- o Ammonia leakage for 140 hours would definitely be detected by smell.
- o Temperatures of 200 to 250°F should not produce reaction with CO, F22, F113, toluene, DCM, or xylene.
- o Stainless steel chamber thoroughly cleaned prior to test.
- o Quantity of ammonia that could be absorbed in atmospheric water calculated to be nil-no water found in chamber at end of test.
- o Canister flow calibrated and other contaminants correlate too well for such a large difference in ammonia concentration.

As a result of the checks conducted during and after the test, the reason for the low ammonia concentrations was not uncovered. Considering the fact that ammonia concentrations did rise without any known action being taken by the test crew between 100 and 140 hours, and that a relatively large dip in concentration occurred over the weekend stop at 265 hours, it seems that the likely explanation is ammonia adsorption on some surfaces within the introduction and chamber system.

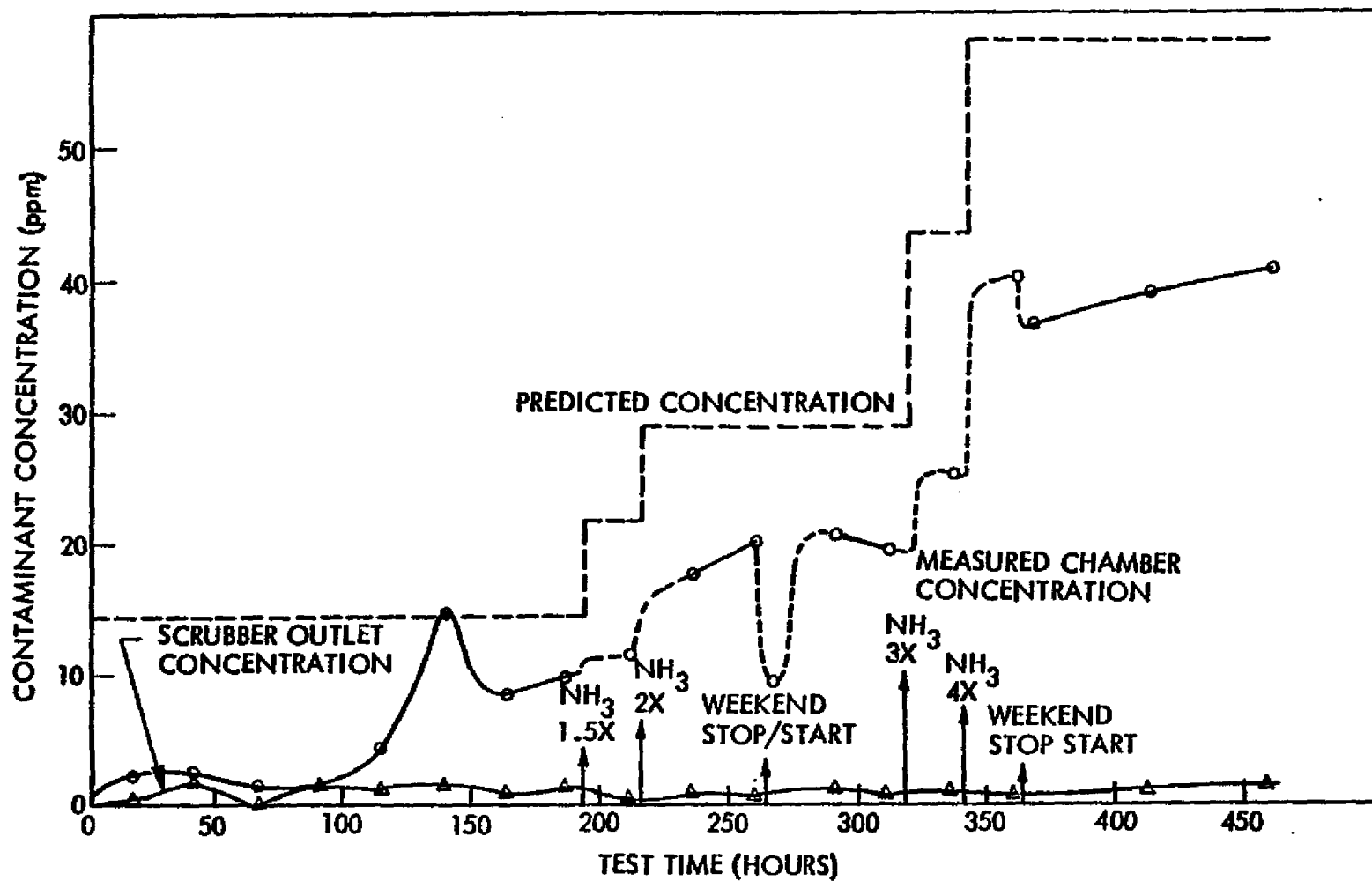


Fig. 2 Spacelab Scrubber Development Test Results - Ammonia

Performance of the ammonia removal bed was excellent. Ammonia removal by acid treated charcoal has not been quantified nor have the dynamics of the process been analytically or experimentally determined. It has been the experience of Lockheed that 100 percent removal per pass is very difficult to achieve, but that 90 percent can be achieved by proper design of bed velocity and bed length. The approach to establishing the quantity of acid to be used has been to provide far more than is stoichiometrically required to neutralize the ammonia introduced into the bed. The penalties for this over design are small, because the total acid weight is small and the acid only slightly reduces the adsorption capacity of charcoal for other contaminants. Only seven percent of the available phosphoric acid was used during the 460 hours of testing. The results of the test that showed ammonia removal capability far in excess of that required for a seven day Spacelab mission is not too surprising. The high removal efficiency experienced during the later half of the test when ammonia inbleed rates were greatly increased, yet bed outlet concentrations remained low (<2 ppm), is however surprising. Normally outlet concentrations between 4 and 8 ppm would have been expected. The relatively large amount of acid treated charcoal and the low bed flow of 1.5 cfm (≈ 4.3 fpm superficial velocity) may be the reason for such good bed efficiency. The MSFC test results do compare favorably with the equivalent Lockheed test results. Early ammonia breakthrough was experienced during the initial Lockheed Scrubber development test, but after increasing the acid loading from 1 to 2 millimole per gram of charcoal and increasing the quantity of acid treated charcoal from 2 to 3 pounds, the ammonia removal performance was very similar to that achieved by MSFC. The following table compares the test results. (See page 21.)

Test Results - Carbon Monoxide

Figure 3 plots carbon monoxide concentrations versus test time for the Space-lab Scrubber development test. The carbon monoxide chamber concentration was greater than predicted for the entire test period. Generally, it was between 1 to 4 ppm greater than the predicted 14.9 ppm. The cause of peaks greater than 19 ppm were known to be inbleed flowrate greater than planned. The 2 to 4 ppm increase could have resulted from inaccuracies in the inbleed

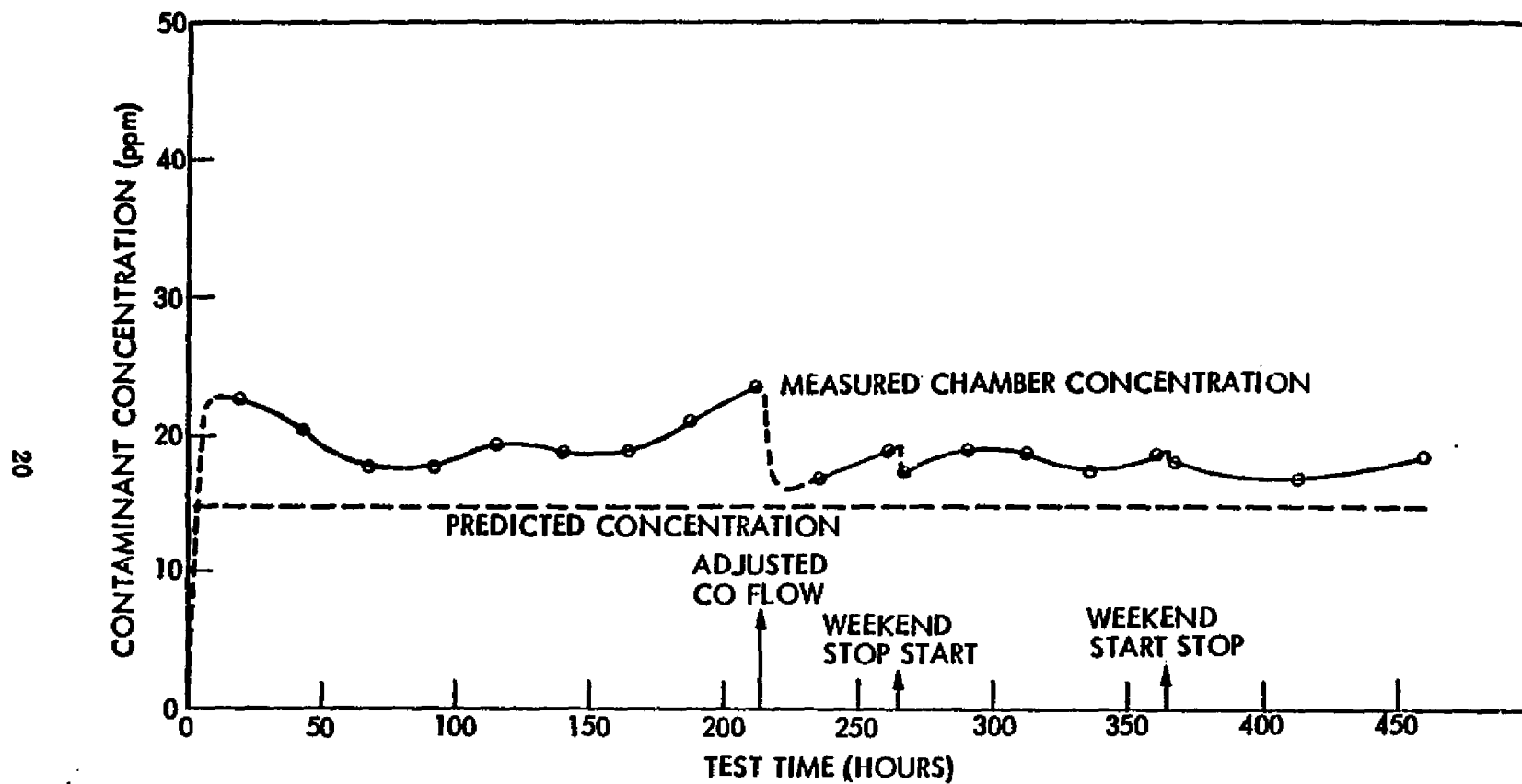


Fig. 3 Spacelab Scrubber Development Test Results - Carbon Monoxide

Comparison of Lockheed and MSFC Ammonia Removal Test Results

	<u>Lockheed Test*</u>	<u>MSFC Test</u>
Weight of Acid Treated Charcoal (lb)	3	4
Acid Treatment (millimole/gm charcoal)	2	2
Total Acid Load (mg)	268,000	356,000
Acid Capacity for Ammonia (mg)	139,000	185,000
Ammonia Introduced into Bed (mg)	17,800	12,431
Total Hours of Testing with Ammonia	504**	460
Ammonia Removal Efficiency at End of Test (%)	92-100***	96.3
Charcoal Bed Flow (cfm)	4	1.5

*Lockheed Development Test No. 2 (Increased H_3PO_4 Loadings)

**Time to Last Ammonia Reading

***Last Reading Showed 100%, Previous Readings Averaged 92%

system or higher than anticipated bed outlet concentrations. The carbon monoxide prediction was based on a catalyst bed efficiency of 90 percent. Early test results showed catalyst bed outlet concentrations near 5 ppm for a removal efficiency of 78 percent. Sensitivity of the carbon monoxide concentration measuring system prevented quantification of the reading below 4 ppm, so that removal efficiency could not be determined after 42 hours of testing when it fell below that level. Lockheed test data showed that for a contact time of 1.1 seconds obtained in the MSFC tests CO conversion efficiency should have been 100%. Bed channeling is the most likely explanation of the lower catalyst bed efficiency during the test.

Although initial catalyst bed efficiencies were lower during the MSFC test than during the Lockheed tests, the bed did not poison as did the Lockheed bed. The MSFC bed performance remained essentially constant for the 460 hours of testing while the Lockheed bed dropped from 100 percent CO conversion to about 40 percent conversion in the same time interval. Two significant differences in testing should be noted. (1) The MSFC test flow was 1.5 cfm versus 4.0 cfm for the Lockheed test. Both contact times (1.1 seconds for MSFC and 0.4 seconds for Lockheed) resulting from these flows should produce 100 percent conversion, but with longer contact times a greater amount of poisoning can be allowed before a drop in bed efficiency will occur. Also 4 cfm will cause more poisons to be

forced into the catalyst bed. (2) The Lockheed tests were run in an open-loop mode, which has certain advantages over closed-loop testing, but does allow contaminants present in the room to be introduced into the system. During the Lockheed tests the "weekend" effect was noted, where CO catalyst bed performance improved during the weekend and degraded during the week. The Lockheed test laboratory is located in a building where a relatively large amount of solvents and degreasers are used during the week. The open-loop test mode that introduces other contaminants into the system may be a contributing factor in the differences between MSFC and Lockheed test results.

Test Results - Freon 22

Freon 22 chamber concentrations during* the test are presented by Figure 4. They were generally less than predicted with the chamber concentration after 265 hours of testing at 77 ppm compared to a predicted value of 108 ppm. Based on an inbleed rate of 21.48 mg/hr, approximately 5700 mg of F22 were introduced into the test chamber. Only 598 mg were accumulated in the chamber air, leaving about 5100 mg of F22 absorbed by the charcoal. Although F22 is not well absorbed by charcoal and was, as expected, in breakthrough throughout the test, the high allowable concentration allows a considerable amount of it to be absorbed (almost 90 percent of that introduced in this case). The difference in total quantity of F22 absorbed between predicted and actual values is only 256 mg or less than five percent of that introduced into the chamber. The measured chamber concentration was below the prediction, so the computer program techniques are on the conservative side, more than five percent, because ninety percent of the F22 was removed at 77 ppm instead of 110 ppm as predicted.

Test Results - Toluene and Xylene

Figure 5 presents measured toluene and xylene concentrations for the 265 hours of testing. Measured concentrations were close to predicted levels. Bed outlet concentrations were zero for both contaminants for the first 90 hours of testing and then rose to 0.45 ppm for toluene and 0.12 for

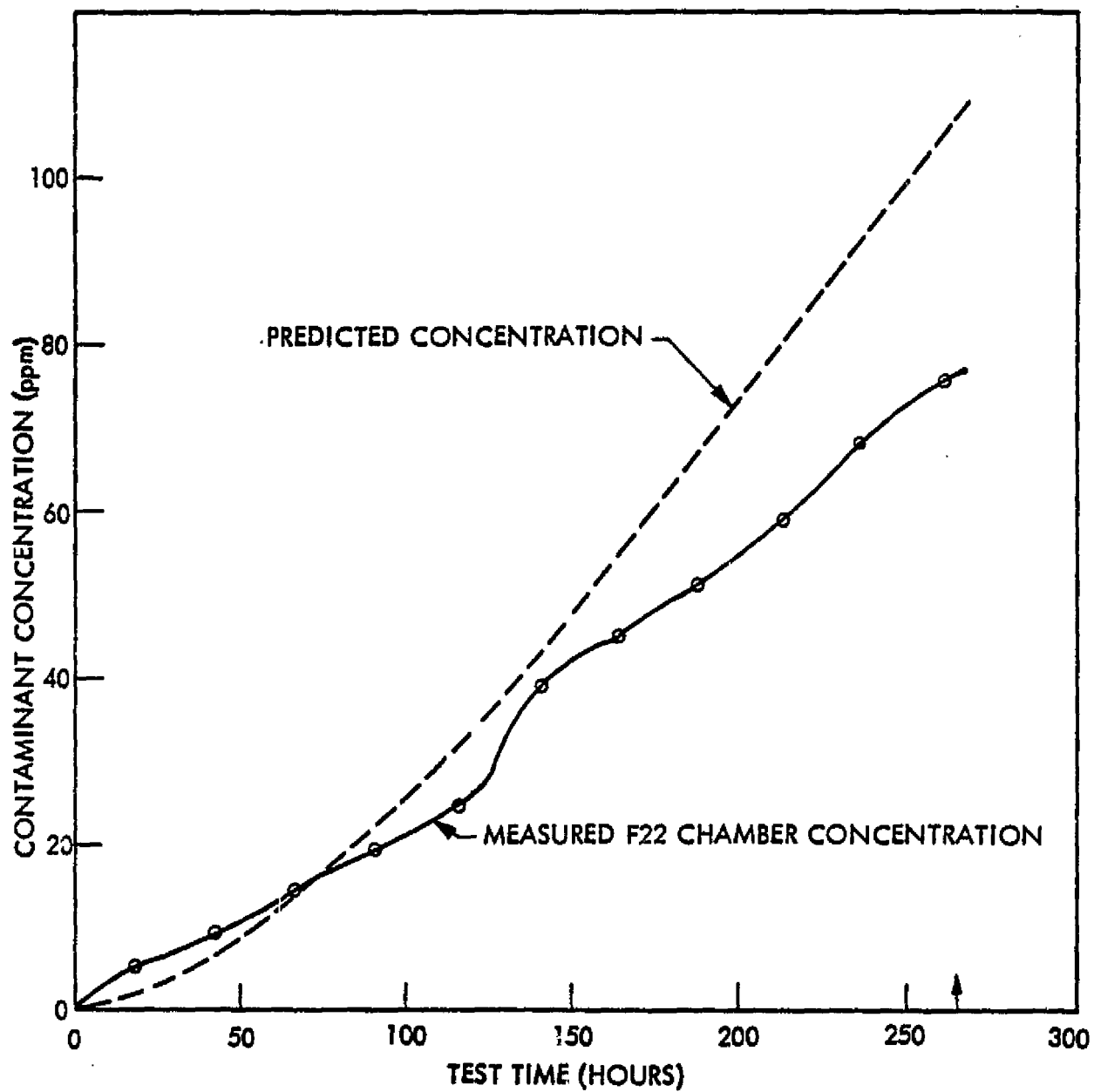


Fig. 4 Spacelab Scrubber Development Test Results - Freon 22

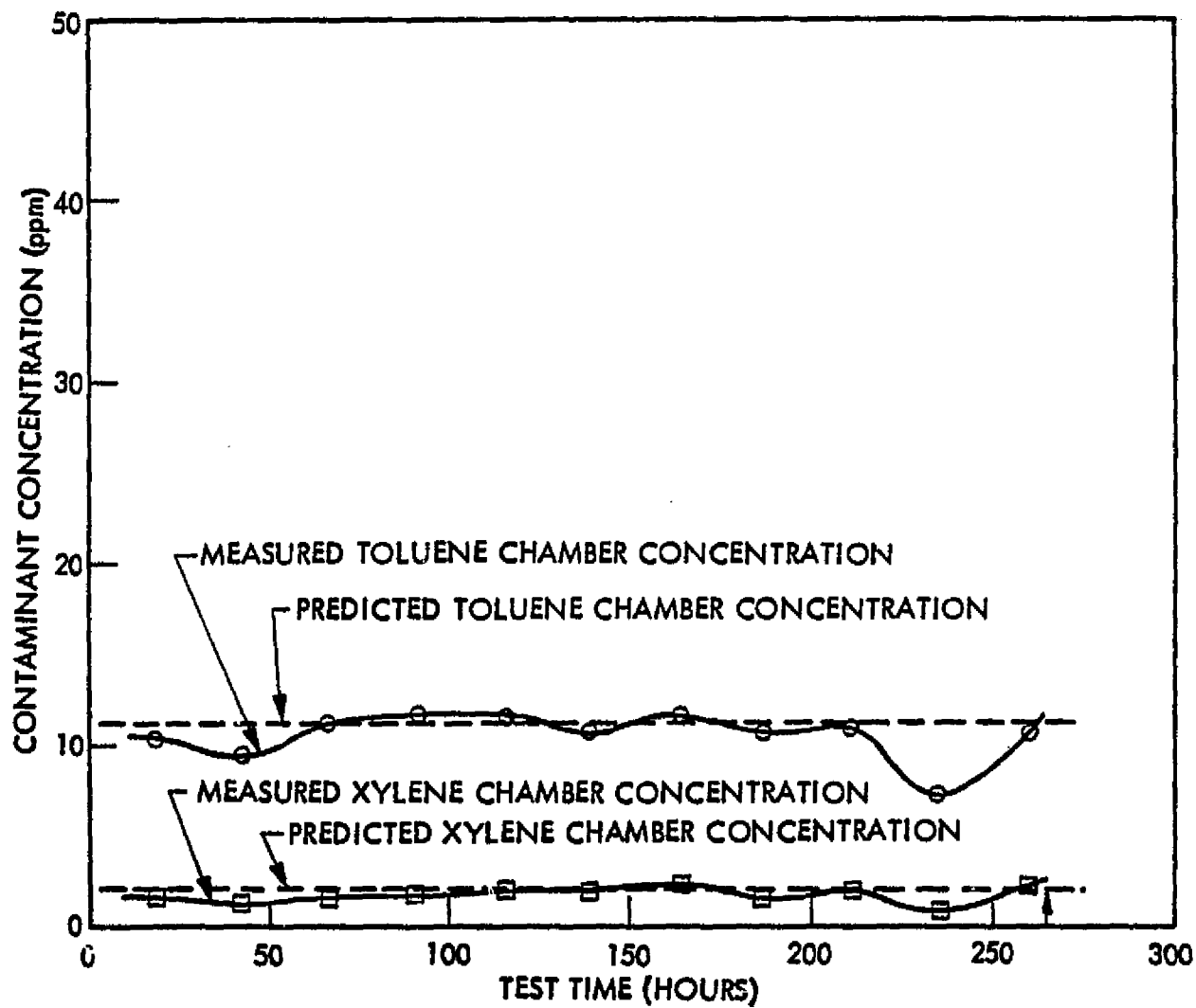


Fig. 5 Spacelab Scrubber Development Test Results - Toluene & Xylene

xylene at the conclusion of the test. Bed efficiencies were approximately 95 percent for both contaminants at the end of the test, compared to a constant 90 percent used by the computer. With such high bed efficiencies, the only reason for changes in contaminant chamber concentrations is a variation in inbleed rates assuming bed flow is constant.

Test results - Dichloromethane and F113

Figure 6 presents dichloromethane and Freon 113 chamber concentrations measured during the test as compared to predicted levels. Measured levels were fairly close to predicted levels with two exceptions, one occurring about 140 hours and the other after 210 hours. The dichloromethane and Freon 113 mixture flow rates were found to be high and were adjusted downward at 144 hours which accounts for the hump in the curves near that time. The second exception is that the computer program predicted breakthrough of dichloromethane at 210 hours, which did not occur, i.e. the charcoal capacity for dichloromethane is greater than predicted. The flow of F113 and dichloromethane were not introduced into the chamber until 52 hours because of a leak in the introduction system. They were then set at twice scheduled rates to help compensate for the lost time. At 74 hours they were reduced to normal schedule rates and were held at that value for the remainder of the test.

Review of Scrubber Design

The Spacelab Scrubber development test proved the design to be adequate for all tested contaminants and in many instances showed the design to be on the conservative side. CO catalyst performance exceeded expectations with respect to poisoning in that no degradation in performance was noted during 460 hours of testing. The ammonia removal bed showed a big margin of excess providing an efficiency of 96 percent after 460 hours of testing. Freon 22 was removed at lower concentrations than predicted (77 ppm at 265 hours compared to a prediction of 108 ppm). The charcoal bed's capacity for dichloromethane was greater than predicted with no breakthrough in 265 hours of testing. Steps could be taken to reduce Scrubber capacity in all three areas, but the cost of testing, analysis, and redesign would not be

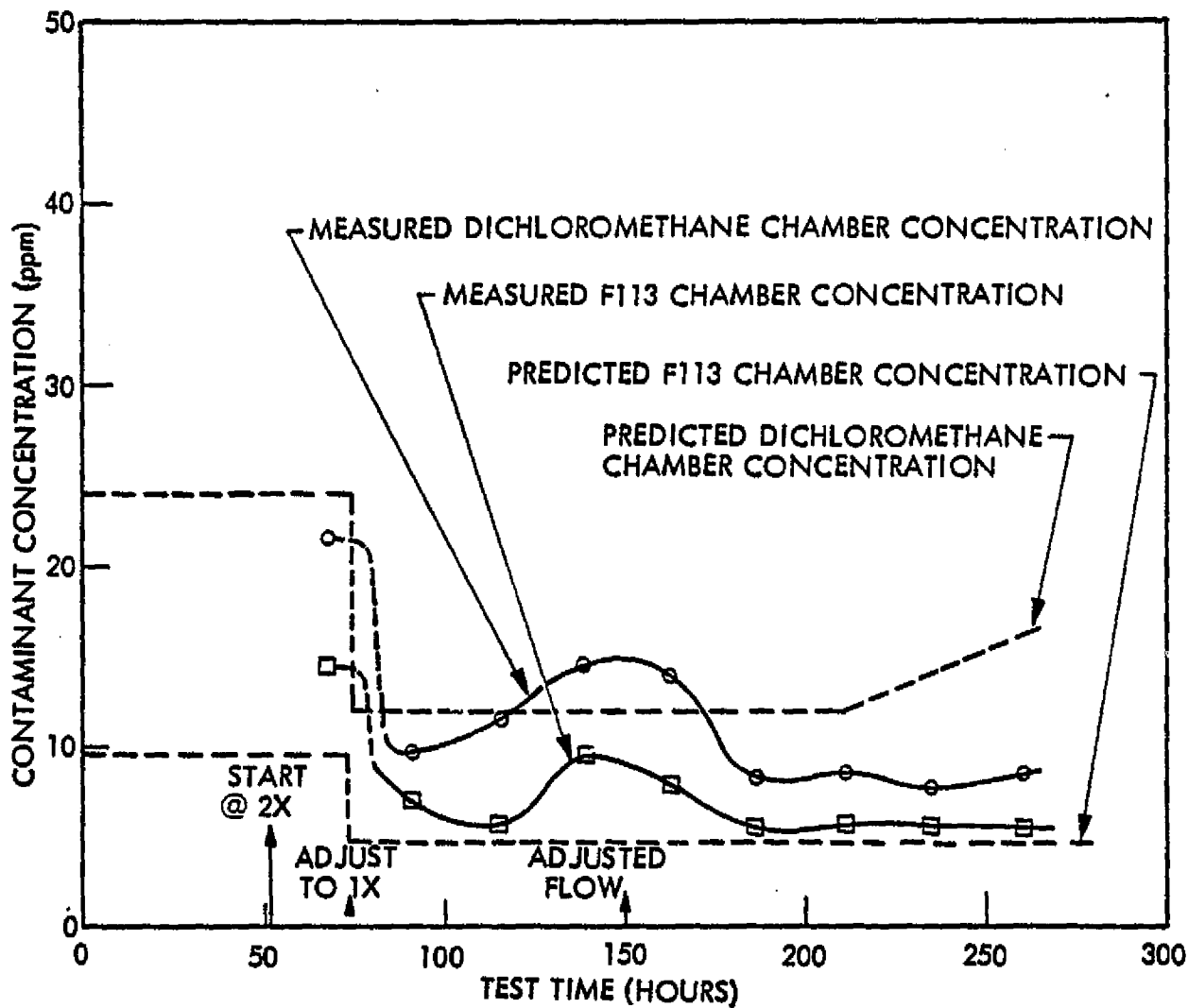


Fig. 6 Space Scrubber Development Test Results - F113 & Dichloromethane

worth the small weight savings of catalyst, charcoal, and acid that could be realized. The conservativeness in the design is valuable in light of the uncertainties in the contaminant load model. Therefore, it was recommended that no changes be made to the Spacelab Scrubber design.

QUALIFICATION TEST

In preparation for the qualification test, discussions were held with NASA-MSFC personnel concerning the means of determining acceptable scrubber performance. Bed removal efficiency, total quantity of contaminant removed and test chamber contaminant concentration were considered. It was decided that the best measure of bed performance for all contaminants was the test chamber contaminant concentrations. The qualification test was run from March 21 through March 30, 1979 for 214 hours. Some problems with chamber temperature control forced chamber temperature down to 19°F between 81 and 93 hours. Carbon monoxide concentrations were somewhat higher than for the development test showing higher bed outlet concentrations. The chamber carbon monoxide concentrations responded to variations in chamber temperature and inbleed rates, as would be expected with a major upset during the uncontrolled drop in chamber temperature to 19°F. Carbon monoxide concentration rose to a high of 28.1 ppm during this period. Poisoning did not seem to take place with bed efficiency at 189 hours and 69 hours nearly equal. The bed performance for CO oxidation was not as good during the qualification test as it was during the development test. This could be an indication of a lower catalyst activity or some bed channeling. The difference in performance was not large, however.

Ammonia inbleed rates were varied during the test to evaluate the ammonia removal system performance under varying load conditions. The chamber concentrations correlated well with the development test with high ammonia removal efficiency throughout the test.

Freon 22 concentration rose to a value of 56.6 ppm at 166 hours compared to a value of 46 ppm for the development test and a predicted value of 56 ppm.

Toluene concentrations varied during the test but averaged approximately 10 ppm compared to a predicted value of 11.2 ppm. Xylene concentrations averaged

1.5 ppm during the test compared to a predicted value of 2.1 ppm. Dichloromethane concentrations ran approximately 10 ppm following some initial adjustments. Predicted value was 12 ppm. Freon 113 concentrations average between 3 and 4 ppm compared to a predicted value of 4.8 ppm.

The conclusions reached as a result of the qualification test review were that although the CO catalyst bed performance was not as high as desired the Scrubber performed very well and demonstrated the ability to handle the contaminants at greater than predicted generation rates. Ammonia removal margins are particularly greater than required.

COMPUTER PROGRAM MODIFICATIONS

Several computer program modifications were made during the contract period. The changes fall into two categories:

- o Changes implemented to correct a specific failure mode of the program.
- o Changes implemented to reduce the run time of the program.

Intermittent Low Concentrations

This problem was characterized by low concentrations, of the order of 10^{-5} , being interspersed between concentrations having the correct order of magnitude during program runs. This phenomenon is very well illustrated by Table 6, in which every contaminant experiences the problem.

The problem was found to occur by using an incorrect charcoal capacity. The charcoal capacity used was calculated only once during the first iteration within a time increment. By simply recalculating the charcoal capacity every iteration, the problem was solved. Another benefit realized by this change was that some other oscillations were dampened out. For example, in Table 6, xylene appears to be oscillating around 8.9 mg/m^3 . The correction reduced this to a properly increasing function.

Nonconvergent Solution

After making computer runs for several cases, it was observed that occasionally a time increment would be reached in which convergence would not occur and the run was aborted. The nonconvergence was caused by a small number of contaminants experienced a cyclic pattern, as shown below:

<u>Iteration #</u>	<u>(mg) Acetaldehyde</u>		<u>(mg) Methyl Chloride</u>	
	<u>Assumed</u>	<u>Obtained</u>	<u>Assumed</u>	<u>Obtained</u>
49	.15798279	.16129023	.91049369	.91049370
50	.15798279	.16129017	.91049369	.91049370
51	.15798279	.13606691	.91049309	.70099182
52	.15798279	.16129017	.91049309	.91049370
53	.15798279	.16129011	.91049369	.91049370
54	.15798279	.13606691	.91049369	.70099182

Table 6 Daily Concentration Data

		11	36	37	68	78	79	171	175
		METHYL	XYLENE	TOLUENE	DICHLOR	FREON 2	FREON 1	AMMONIA	CARBON
DAY	HRS								
0	0,0	,000E+00	,000E+00	,000E+00	,000E+00	,000E+00	,000E+00	,000E+00	,000E+00
0	0,5	,509E+01	,287E+02	,138E+03	,135E+03	,698E+02	,117E+03	,249E+02	,547E+02
1	0,0	,304E+05	,428E+05	,256E+05	,252E+05	,283E+03	,436E+05	,371E+05	,407E+05
1	0,5	,185E+02	,156E+02	,746E+02	,734E+02	,419E+05	,635E+02	,135E+02	,297E+02
2	0,0	,463E+05	,423E+01	,203E+02	,199E+02	,279E+03	,172E+02	,367E+01	,805E+01
2	0,5	,277E+01	,125E+02	,599E+02	,589E+02	,375E+03	,509E+02	,108E+02	,238E+02
3	0,0	,231E+02	,648E+01	,310E+02	,305E+02	,244E+05	,264E+02	,562E+01	,123E+02
3	0,5	,259E+05	,109E+02	,520E+02	,512E+02	,279E+03	,443E+02	,943E+01	,207E+02
4	0,0	,164E+02	,767E+01	,367E+02	,361E+02	,558E+03	,312E+02	,665E+01	,146E+02
4	0,5	,438E+05	,100E+02	,479E+02	,471E+02	,169E+03	,407E+02	,868E+01	,190E+02
5	0,0	,204E+02	,830E+01	,398E+02	,391E+02	,448E+03	,338E+02	,720E+01	,158E+02
5	0,5	,243E+05	,954E+01	,457E+02	,449E+02	,727E+03	,389E+02	,828E+01	,182E+02
6	0,0	,204E+02	,864E+01	,414E+02	,407E+02	,266E+03	,352E+02	,749E+01	,164E+02
6	0,5	,243E+05	,930E+01	,445E+02	,438E+02	,545E+03	,379E+02	,807E+01	,177E+02
7	0,0	,277E+01	,882E+01	,422E+02	,415E+02	,307E+05	,359E+02	,765E+01	,168E+02

The problem was traced to the following steps in the ICHAR routine:

- (a) For $\Delta A > 16$, the mass of charcoal required was not calculated by a residual value remained (from previous calculation).
- (b) When searching for the contaminant with the minimum mass of charcoal required, contaminants with $\Delta A > 16$ were searched and the meaningless value was used.

The problem was corrected by not allowing contaminants with $\Delta A > 16$ to be searched.

New Convergence Scheme

A new convergence scheme was developed that decreased the number of iterations required within a time increment. The scheme involves estimates of the mass remaining, as delineated below:

Iteration 1, first time increment:

Mass Assumed Remaining = Half of Mass Generated

Iteration 1, subsequent time increments:

Mass Assumed Remaining = Mass in Cabin at Beginning of Increment

Iteration 2:

Mass Assumed Remaining = 0.8 (Mass Assumed, Iteration 1)
+ 0.2 (Mass Calculated Remaining, Iteration 1)

Iteration 3, and subsequent:

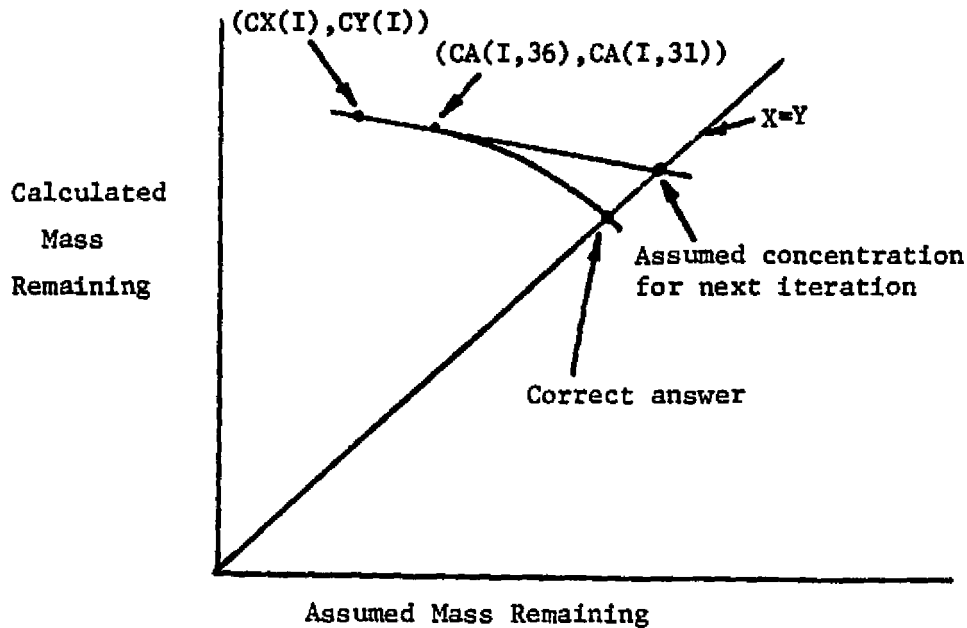
The new convergence scheme uses the method of secants after two trials to estimate the convergent concentration.

Specifically, for iteration just finished

Assumed Amount Remaining = CA(I,36)

Calculated Amount Remaining = CA(I,31)

For the iteration before that, these quantities are represented by CX(I) and CY(I) respectively (I = contaminant ident). Thus we have a graph that looks like this:



The line is extended until it meets the line X=Y (assumed = calculated).

The equation of the line is

$$Y = CY(I) + (CA(I,31) - CY(I)) \left[\frac{X - CX(I)}{CA(I,36) - CX(I)} \right]$$

but since X=Y

$$X = \frac{CX(I) + (CA(I,36) - CX(I))(CX(I) - CY(I))}{CA(I,31) - CA(I,36) - CY(I) + CX(I)}$$